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6 A COMPARISON OF NOISE CLEANING TECHNIQUES FOR COLOR IMAGES.

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ABSTRACT

An earlier report compared a number of iterative local noise cleaning techniques as applied to grayscale images. The present report provides some additional discussion of the grayscale results, and also applies several of the better methods to a color image of a house. Noise cleaning on each individual color component is compared with noise cleaning on the color vectors themselves. Results for two color coordinate systems, RGB and UVW, are also compared.

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1. Introduction

In an earlier report [1], a number of iterative local noise cleaning techniques were compared subjectively. The present report provides some additional comparative results for grayscale images, and also applies several of the better methods to a color image.

The methods compared in [1] are briefly summarized below. In all of them (except as noted) a new gray level P' for the point P is computed as a function of the gray levels in its 3-by-3 neighborhood N(P), and this process is iterated. For the detailed definitions of the methods see [1] and its references.

1. Mode filtering: P' is the most frequently occurring gray level in N(P).
2. Median filtering: P' is the median gray level in N(P).
3. E^k: P' is obtained by averaging P wth the k points of N(P) that are closest to it in gray level.
4. Gradient smoothing: P' is the average of those points of N(P) that have lower gradient values than P.

5a. Selective averaging 1: P' is the average of N(P) provided P differs from at least 6 of its neighbors by at least t.

5b. Selective averaging 2: P' is the average of N(P) provided the edge strength at P is less than t; otherwise, P' is the average of the two neighbors in the direction along the edge.

5c. Selective averaging 3: Analogous, but using four directional edge masks, rather than differences in two perpendicular directions, to determine edge strength and direction.

6. Maximum homogeneity smoothing: Five 4x4 neighborhoods that surround P are used; P' is the average of that neighborhood which is most homogeneous.

7. Neighbor weighting (1,2): P' is a weighted average of N(P). (The definitions of the weights are somewhat complicated, and will not be reproduced here.)

8. Weighted averaging: P' is a weighted average of P and the mean of N(P), where the weight given to P depends on how high the local image variance is relative to the overall image variance. (This method was not iterated.)

9. Kalman filtering: The P' values are computed sequentially; P' is a weighted average of P and the P' values of the north, west, and northwest neighbors of P, where the weights depend on the autocorrelation of the image, and also on a parameter η. This computation is done in a single TV raster scan of the image. An analogous computation is also done using the south, east, and southeast neighbors, and the two resulting P' values are averaged to obtain a final value. This process was not iterated.

2. Grayscale results

The methods in [1] were applied to the two images shown in Figure 1. Figure 1a is a 128x128 image of an octagon of gray level 33 (on a 0-63 scale) on a background of gray level 28; Figure 1b is the same image with Gaussian noise of $\mu=0$, $\sigma=5$ added. Figure 1b is a 127x127 portion of a LANDSAT image, and Figure 1d shows it with Gaussian noise of $\mu=0$, $\sigma=8$ added. Figure 2 shows the histograms of the four images in Figure 1. Note that the peak structure of the non-noisy histograms is obliterated by the noise.

Histograms of the images obtained by noise cleaning are shown in Figures 3-11 in accordance with the following table:

Method:	1	2	3	4	5a	5b	5c	6	7a	7b	8	9
Figure:	3	4	5	6	7a	7b	7c	8	9a	9b	10	11

(The cleaned images themselves can be found in [1], and will not be shown here.) It is seen that most of the methods do restore the peak structure to a great extent.

Tables 1 and 2 give mean squared error results for the octagon and LANDSAT images respectively. The errors are those which result when the original, non-noisy images are subtracted from the processed ones.

Results for the octagon are misleading in that the values are all quite small, especially when compared to the mean squared error of the noisy octagon. The loss of the border of the octagon is apparently outweighed by improvements made in the rest of the image. The results might indicate that subjectively ranking the processed images would be difficult. Consequently, these values will not be used in evaluating the methods.

In almost all cases, the fourth iteration has the lowest value. However, in visually examining the pictures, the third iteration seemed to be the best representative of a method's performance. Thus, the values for the third iteration will be used in comparing the methods.

Of the best methods, median filtering and the first neighbor weighting method have low mean squared error values, while gradient smoothing has a large value compared to the above methods. As noted in [1], this is probably due to the asymmetry introduced when a 2x2 Roberts gradient is computed and operations are performed on a 3x3 neighborhood.

If a value for E^5 is interpolated from those for E^4 and E^6, it would fall in the same range as that for the first selective averaging method, which was judged to be somewhat noisier than the best methods. Except for Kalman filtering, mean squared error results confirm that the poor methods are poor.

The histograms also confirm some of the subjective results. Histograms of the results of gradient smoothing and median filtering of the LANDSAT image have shapes which most resemble the histogram of the non-noisy image. Those for E^6 and the first selective averaging method resemble it a little less. The histogram of the octagon for neighbor weighting method 1 has two prominent peaks, but histograms of other methods which did not perform as well also had this characteristic.

Mean squared error and histograms are not very reliable criteria by which to judge noise cleaning methods. One reason is that they give little or no indication as to the degree of blurriness that may be present in an image. The mean squared error tended to become smaller with each successive iteration, but the image often became more blurred.

The peaks on a histogram indicate the different regions which are present in a picture. Thus, the peaks will be most pronounced when the noise is quite different from the picture detail. Fine detail is not represented well in a histogram. The peaks of the histogram of the octagon represent it and the background. The large peaks represent the different types of fields. Many of the histograms of the octagon have two prominent peaks but the corresponding images were blurred. Results for the LANDSAT image were similar. The histograms do, however, indicate how much smoothing a method is doing between successive iterations. For example, median filtering seems to smooth at a faster rate than gradient smoothing.

Although one image may look better than another, the mean squared error of the worse image may be lower, e.g., averaging gives a lower mean squared error than median filtering for the LANDSAT image. This could occur because several of the differences are large compared to the rest. This may not be detectable by eye since the locations of these "wild" differences are probably random. On the other hand, shifts in the picture detail, as in gradient smoothing, will be detected through mean squared error. This would be of interest in cases where the position of the picture detail is an important factor.

Method	Iteration 1	2	3	4
Mode	14.952	12.017	11.436	11.197
Gradient	7.736	3.628	2.804	2.540
Median	4.816	2.955	2.328	2.033
E^2	14.499	12.631	11.984	11.641
E^4	9.094	6.346	5.341	4.836
E^6	5.217	3.054	2.355	1.863
E^8	3.617	1.744	1.256	1.021
Selective Averaging 1				
t=2	4.487	2.993	2.800	2.767
t=3	6.199	4.876	4.675	4.636
Selective Averaging 2				
t=2	11.504	5.304	2.723	1.756
t=3	10.104	3.972	1.990	1.373
t=4	8.661	2.986	1.640	1.225
t=5	7.348	2.435	1.475	1.156
Selective Averaging 3				
t=2	11.323	4.990	2.512	1.637
t=3	9.588	3.529	1.820	1.324
t=4	7.892	2.651	1.526	1.173
t=5	6.477	2.220	1.408	1.109
Neighbor Weighting 1	5.878	3.073	2.237	1.891
Neighbor Weighting 2	11.945	6.108	3.690	2.635
Maximum Homogeneity Smoothing	2.539	1.376	1.249	1.298
Non-iterative Methods				
Averaging (3x3)	3.316			
Weighted Averaging	3.434			

Kalman Filtering

η = .1-.6	2.005	3.441	5.076	6.854	8.926	11.297

Table 1. Mean Squared Error Results for the Octagon Image (Noisy Octagon: 25.412)

Method	Iteration 1	2	3	4
Mode	50.780	45.060	44.913	44.873
Gradient	26.501	21.660	25.874	32.963
Median	15.122	11.600	11.074	10.894
E^2	40.465	37.062	35.987	35.585
E^4	25.960	19.979	18.164	17.359
E^6	15.375	10.788	9.728	9.371
E^8	13.222	10.597	12.278	13.875
Selective Averaging 1				
t=3	15.337	12.686	12.662	12.675
t=4	17.643	14.683	14.473	14.415
t=5	20.579	17.565	17.123	17.049
Selective Averaging 2				
t=2	38.478	24.425	20.042	18.253
t=3	36.964	22.607	18.639	17.186
t=4	35.401	20.816	17.211	16.100
t=5	33.262	18.993	16.090	15.212
Selective Averaging 3				
t=2	36.676	23.301	18.251	16.128
t=3	35.186	21.145	16.317	16.063
t=4	32.847	18.569	14.782	13.485
t=5	30.520	16.535	13.648	12.927
Neighbor Weighting 1	16.360	10.824	9.776	9.686
Neighbor Weighting 2	37.399	26.568	20.201	17.649
Maximum Homogeneity Smoothing	42.279	42.245	55.805	69.059

Non-iterative Methods						
Averaging (3x3)	9.537					
Weighted Averaging	11.152					
Kalman Filtering						
η = .1-.6	16.373	12.672	13.928	17.116	21.667	27.281

Table 2. Mean Squared Error Results for the LANDSAT Image
(Noisy LANDSAT: 62.918)

3. Results for a color image

3.1 Extension to the color domain

The three methods which performed best on the LANDSAT image, gradient smoothing, median filtering, and neighbor-weighting method 1, were tested on the noisy version of a house picture. The E^5 method was also included; recall that E^4 was a little too noisy and E^6 was a little too blurry.

Two color coordinate systems were used, RGB and UVW. The components of the RGB system are the brightness values of a scene viewed through red, green, and blue filters. UVW is a uniform chromaticity system which attempts to allow for the human viewer being most sensitive to color shifts in blue, and least sensitive to those in green [2]. The UVW components were computed from the original RGB components using the following transformation [2]:

$$\begin{bmatrix} U \\ V \\ W \end{bmatrix} = \begin{bmatrix} .405 & .116 & .133 \\ .299 & .587 & .114 \\ .145 & .827 & .627 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} .$$

The values were then scaled to fall within a 0-63 gray level range.

Next, the question of adding noise to a color picture was addressed. In a multispectral scanner, the radiation received from the terrain passes through three separate filters and is converted to intensity information via three individual channels.

Electronic noise is introduced separately in each channel. Thus, for this study, Gaussian noise ($\mu=0$, $\sigma=5$) was added to each color component (in both coordinate systems).

Noise cleaning was performed separately for each component, and was also performed "vectorially", i.e., in the three-dimensional color space using Euclidean distances.

The non-noisy RGB components of the house picture are shown in Figure 12a; the UVW components are shown in Figure 12c. Figure 12b and 12d are the corresponding noisy components. (Color pictures will not be reproduced here.)

3.2 Discussion of results

For each method, there are four sets of pictures, two for each coordinate system. In the following discussion, figure numbers followed by an a are the results of smoothing separately in each channel ("scalar") in the RGB system and numbers followed by a b are the results of smoothing in color space ("vector") in the RGB system. Figure numbers followed by a c and d are the corresponding results for the UVW system.

The results for all four methods were similar to those obtained using the black and white images. As can be seen in all but the U component images, which are rather dark, the methods cleaned the noise well, but the images were blurred by the third iteration. Figure 13 shows the results of median filtering; Figure 14, gradient smoothing; Figure 15, neighbor weighting method 1; and Figure 16, E^5. E^5 appears to have blurred the least, followed by gradient smoothing, neighbor weighting, and median filtering.

Mean squared error results are presented in Tables 3-6. They are comparable to those for the black and white images. The mean squared error for gradient smoothing is much larger than those of the other three methods which are close in value to each other. Histograms for the pictures in Figures 12-16 are shown in Figures 17 - 21. As before, not much information about the quality of the image can be derived from the histogram.

Differences between the scalar and vector methods are difficult to see. However, the images which were cleaned vectorially appear to require more iterations to smooth out the noise. This can be seen by comparing iterations 2-4 in corresponding pairs of figures. Mean squared error results seem to agree with this observation. The histograms for the vector method have wider peaks than those for the scalar method. The vector method also changed the shape of the large shrub at the left of the blue component picture in gradient smoothing whereas the scalar method did not. The small window in the bottom right of the blue component of E^5 changed shape more with the vector method. This can also be seen in the W component of E^5.

The separate components were combined using a program written for the PDP 11/45 and the results displayed on a color display. The UVW components were converted to RGB before display. The inverse transformation may be responsible for the inferior appearance of the UVW color images, as the information lost when the UVW original was scaled could not be recovered. Scaling was done to keep all the components in the same gray level range. (A discussion of the instabilities of color transformations can be found in [3].)

In the RGB coordinate system, the scalar images were better overall than the vector images. All the images were blotchy although median filtering and gradient smoothing had larger blotches than neighbor weighting and E^5. Vector images were blurrier than scalar. Edges on the large window were fairly straight in the scalar images but were distorted in the vector images. The large bush was bent to the left following vector gradient smoothing. E^5 seemed to perform the best in both systems. The images were the least blurred and edges were less distorted.

The nonprocessed noisy UVW had a very different appearance from the corresponding RGB picture. The noise seemed to be concentrated in randomly distributed clumps rather than points. The images were blotchy and blurry and noisier than those in RGB. The vector processed images appeared to be better than the scalar. The scalar gradient smoothed image had noticeable specks (which were smoothed out by the fourth iteration). In addition, the details were distorted and seemed to smear into each other. The vector images were noticeably less speckled and the detail appeared to be less distorted. In all methcds, the edges in the vector images were less noisy than in the scalar.

Method	Iteration 1	2	3	4
Median Filtering				
Red	6.164	5.068	5.070	5.227
Green	5.655	4.436	4.441	4.568
Blue	6.592	5.795	6.117	6.546
Average	6.137	5.100	5.209	5.447
Gradient Smoothing				
Red	11.610	9.888	12.357	15.282
Green	11.066	9.543	11.734	15.082
Blue	13.131	12.519	16.061	20.604
Average	11.936	10.650	13.384	16.489
Neighbor Weighting Method 1				
Red	6.778	4.829	4.682	4.888
Green	6.523	4.466	4.289	4.487
Blue	6.983	5.272	5.435	5.929
Average	6.761	4.856	4.802	5.101
E^5				
Red	7.993	5.943	5.546	5.500
Green	7.443	5.215	4.725	4.588
Blue	8.147	6.124	5.793	5.732
Average	7.861	5.761	5.355	4.940

Table 3. Mean Squared Error--RGB, scalar smoothing

Noisy Red 25.315

Green 25.187

Blue 25.257

Average 25.253

Method	Iteration 1	2	3	4
Median Filtering				
Red	7.427	6.832	6.987	7.370
Green	6.726	5.727	5.836	5.983
Blue	7.816	7.298	7.715	8.280
Average	7.323	6.619	6.846	7.211
Gradient Smoothing				
Red	11.648	9.672	11.022	13.149
Green	11.388	9.833	11.864	14.217
Blue	13.199	12.757	16.022	20.006
Average	12.078	10.754	12.969	15.791
Neighbor Weighting Method 1				
Red	7.031	5.077	4.997	5.240
Green	6.645	4.595	4.446	4.654
Blue	7.523	5.878	6.061	6.636
Average	7.066	5.183	5.168	5.510
E^5				
Red	8.607	6.484	6.267	6.301
Green	7.928	5.629	5.120	4.970
Blue	9.135	7.030	6.851	6.952
Average	8.557	6.381	6.079	6.074

Table 4. Mean Squared Error--RGB, vector smoothing

Method	Iteration 1	2	3	4
Median Filtering				
U	4.625	3.133	2.719	2.531
V	5.070	3.702	3.425	3.345
W	5.945	5.146	5.304	5.614
Average	5.213	3.994	3.816	3.830
Gradient Smoothing				
U	7.765	4.458	4.129	4.336
V	8.939	5.963	6.393	7.521
W	11.389	10.722	14.320	19.088
Average	9.364	7.048	8.281	10.315
Neighbor Weighting Method 1				
U	5.329	3.039	2.460	2.270
V	5.829	3.486	2.967	2.848
W	6.467	4.720	4.755	5.140
Average	5.875	3.748	3.394	3.419
E^5				
U	6.530	4.354	3.728	3.474
V	7.001	4.771	4.143	3.883
W	7.593	5.622	5.285	5.222
Average	7.041	4.916	4.385	4.193

Table 5. Mean Squared Error--UVW, scalar smoothing

Noisy	U	22.776
	V	24.337
	W	24.834
Average		23.996

Method	Iteration 1	2	3	4
Median Filtering				
U	5.289	3.850	3.548	3.424
V	5.292	3.912	3.674	3.614
W	6.173	5.476	5.600	5.924
Average	5.585	4.413	4.274	4.321
Gradient Smoothing				
U	7.769	4.641	4.453	4.703
V	8.792	5.984	6.665	7.875
W	11.343	10.430	14.191	18.652
Average	9.301	7.018	8.436	10.410
Neighbor Weighting Method 1				
U	5.233	2.929	2.333	2.106
V	5.743	3.379	2.838	2.740
W	6.738	4.913	4.940	5.334
Average	5.905	3.740	3.370	3.393
E^5				
U	6.266	4.103	3.426	3.120
V	6.904	4.669	4.024	3.734
W	8.228	6.138	5.884	5.820
Average	7.133	4.970	4.445	4.225

Table 6. Mean Squared Error--UVW, vector smoothing

References

1. J. Davenport, A comparison of noise cleaning techniques, TR-689, Computer Science Center, University of Maryland, College Park, MD, Sept. 1978.

2. W. K. Pratt, Digital Image Processing, Wiley, NY, 1978.

3. J. R. Kender, Instabilities in color transformations, Proc. PRIP-77, 266-274.

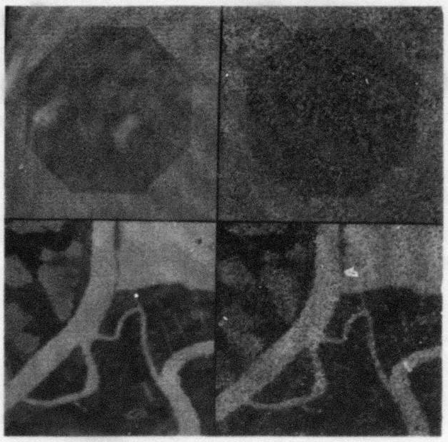


Figure 1.
Original and noisy pictures.

Figure 2. Histograms

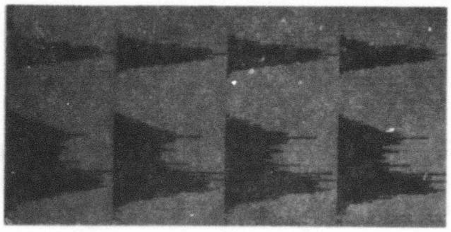


Figure 3. Mode Filtering

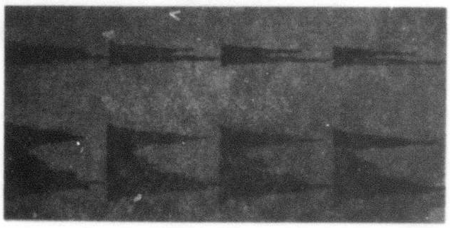


Figure 4. Median Filtering

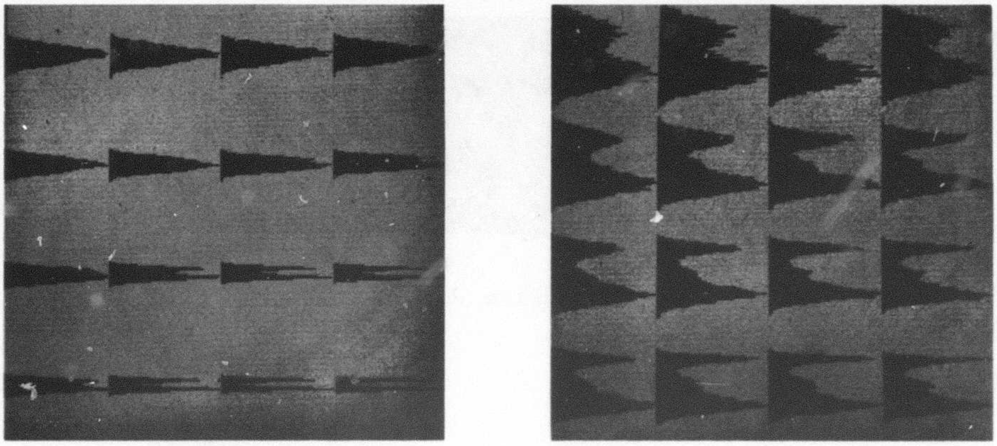


Figure 5. E^k, k=2,4,6,8 from top to bottom.

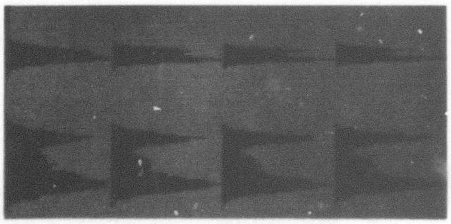
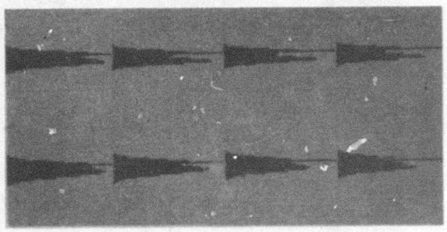
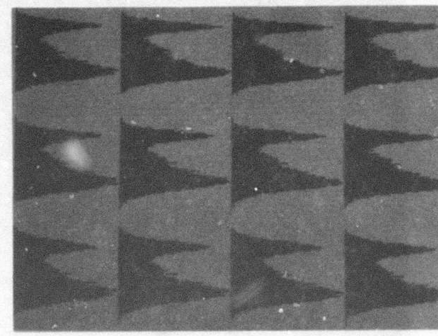


Figure 6. Gradient Smoothing

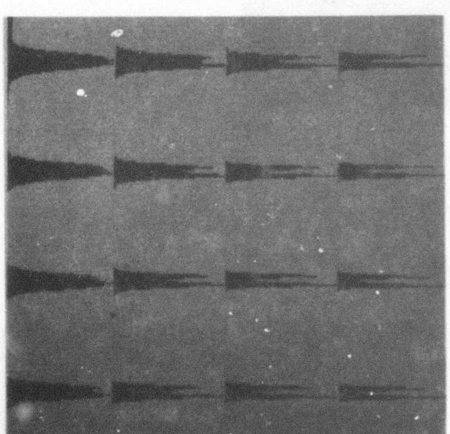


t=2,3



t=3,4,5

Figure 7a. Selective Averaging, Variation 1



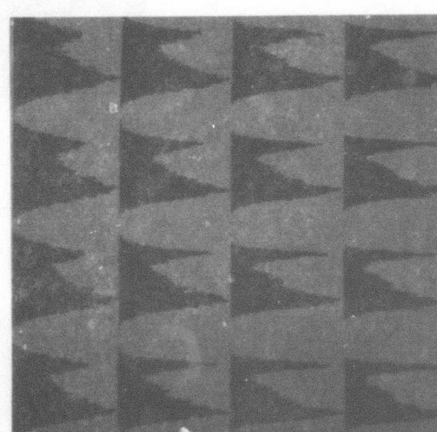


Figure 7b. Selective Averaging, Variation 2, t=2,3,4,5 from top to bottom

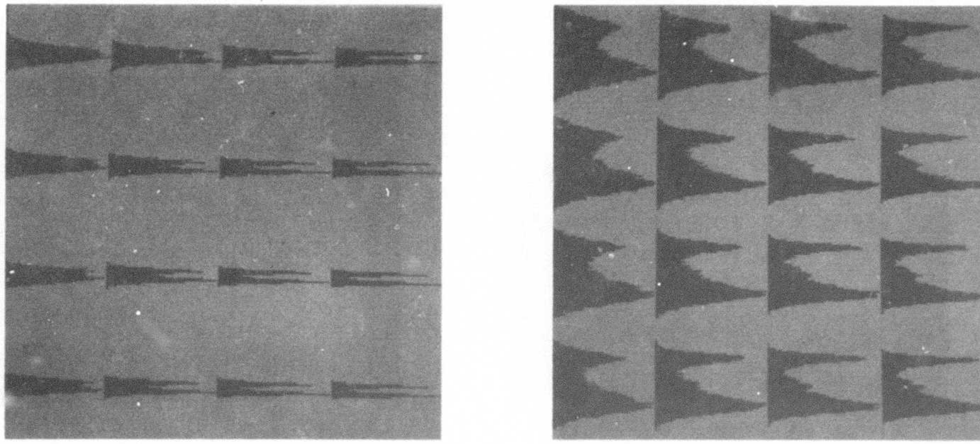


Figure 7c. Selective Averaging, Variation 3, t=2,3,4,5 from top to bottom.

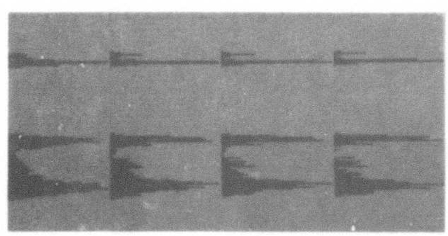
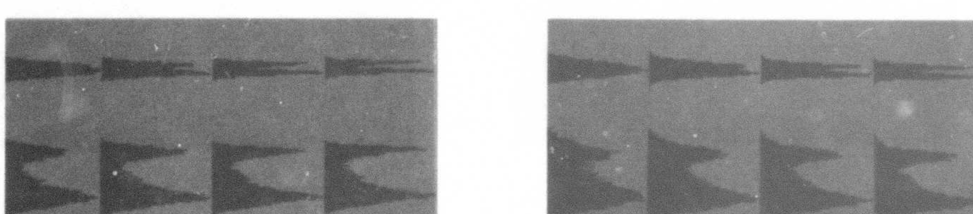


Figure 8. Maximum Homogeneity Smoothing



Method 1

Method 2

Figure 9. Neighbor-weighting

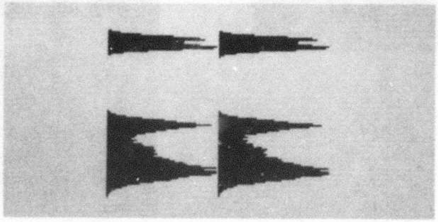


Figure 10. Weighted Averaging

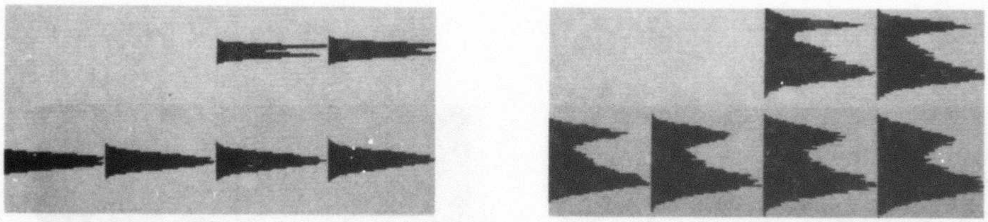


Figure 11. Kalman Filtering, top rows η=0.1,0.2; bottom rows η=0.3-0.6

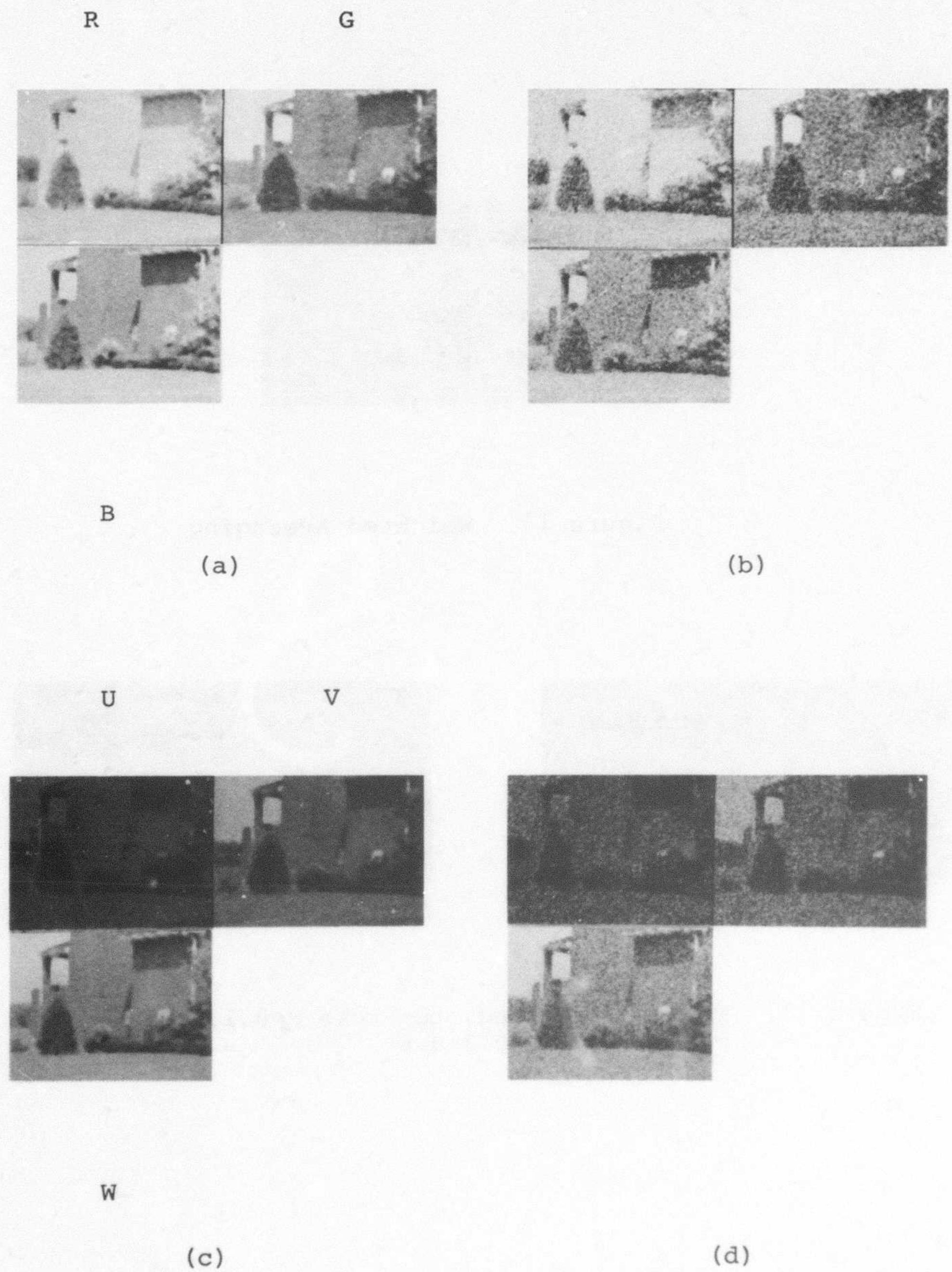
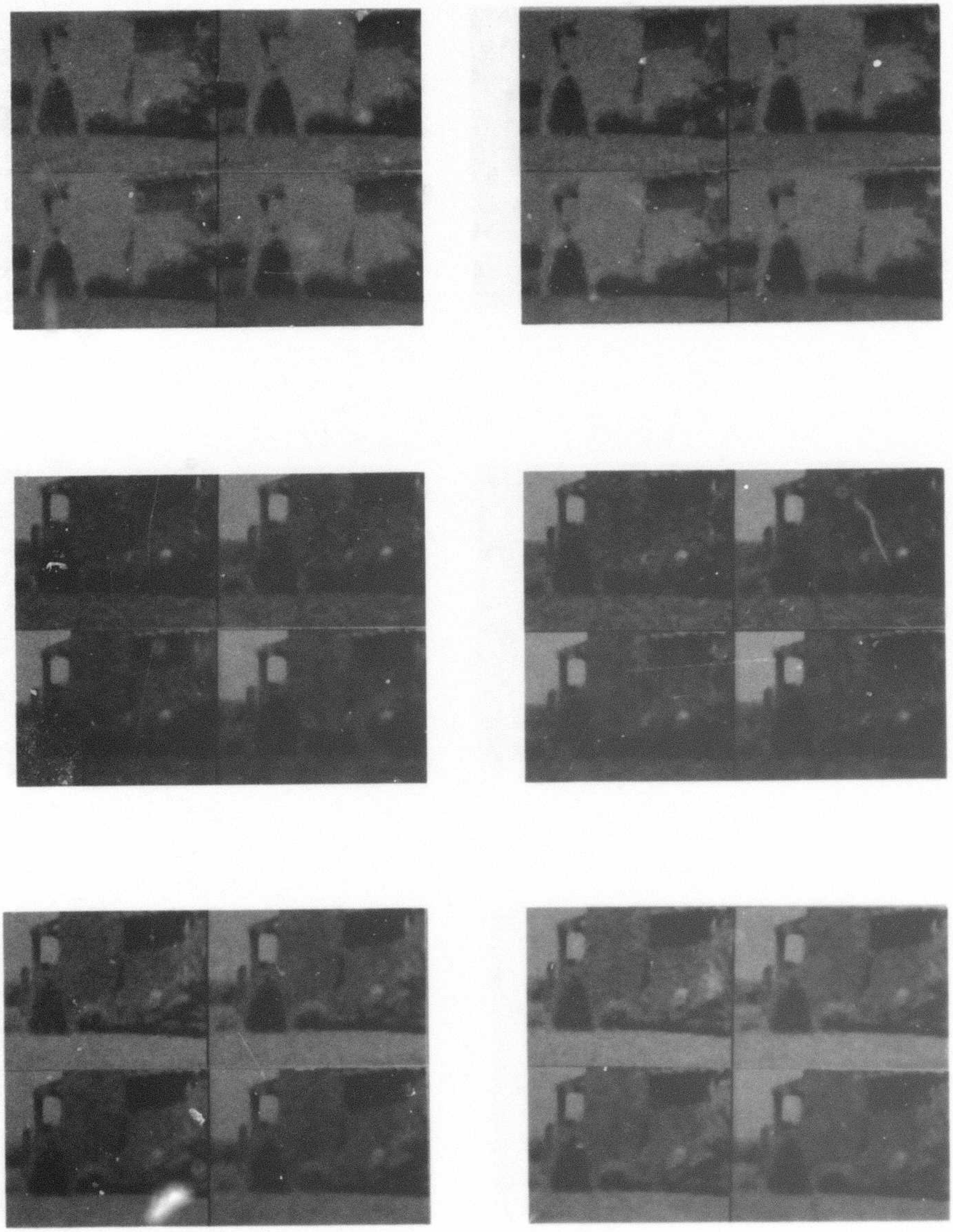
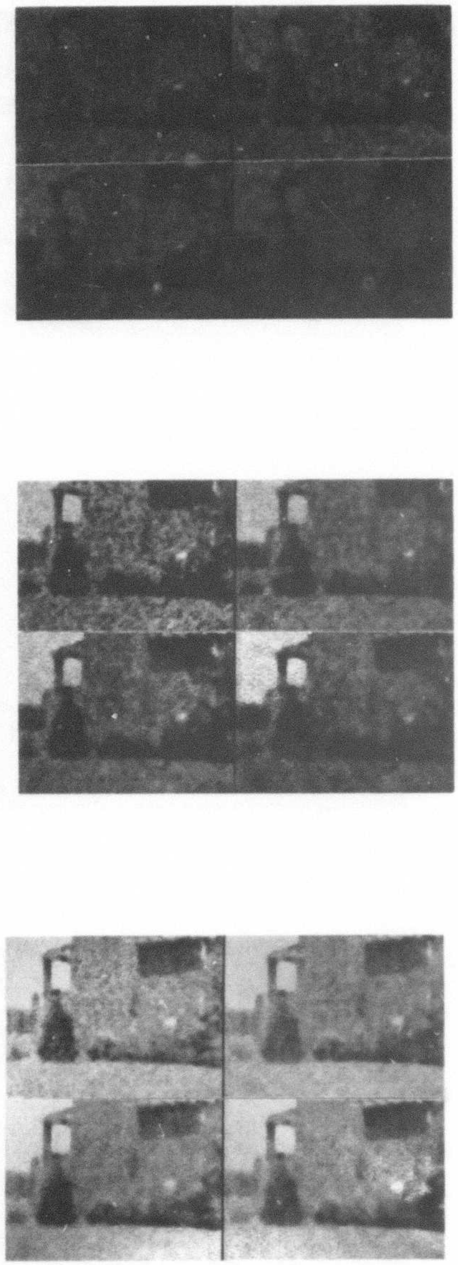


Figure 12. Color Components (a) Original R,G,B, (b) Noisy R,G,B, (c) Original U,V,W, (d) Noisy U,V,W

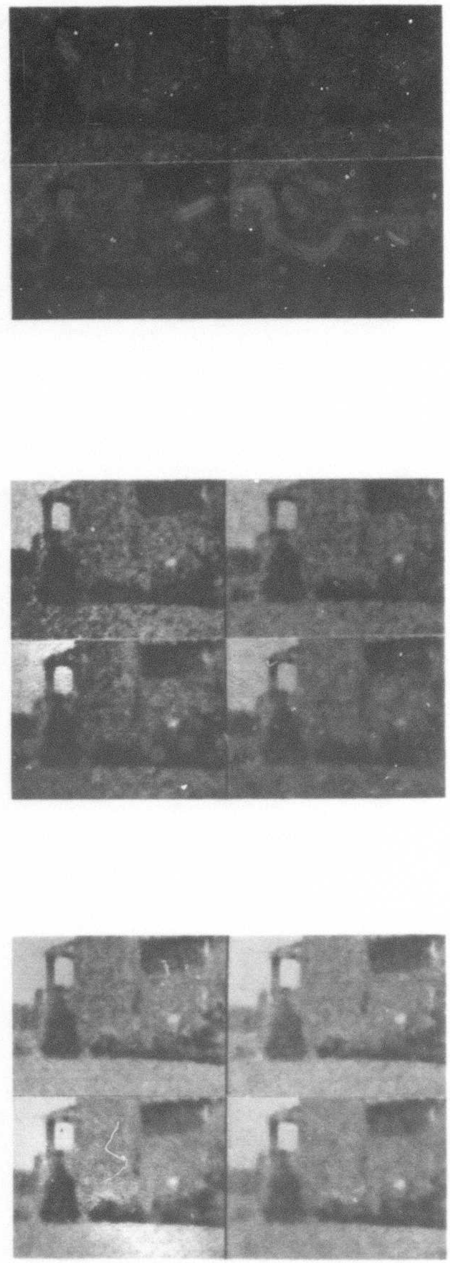


(a) (b)

Figure 13. Median Filtering

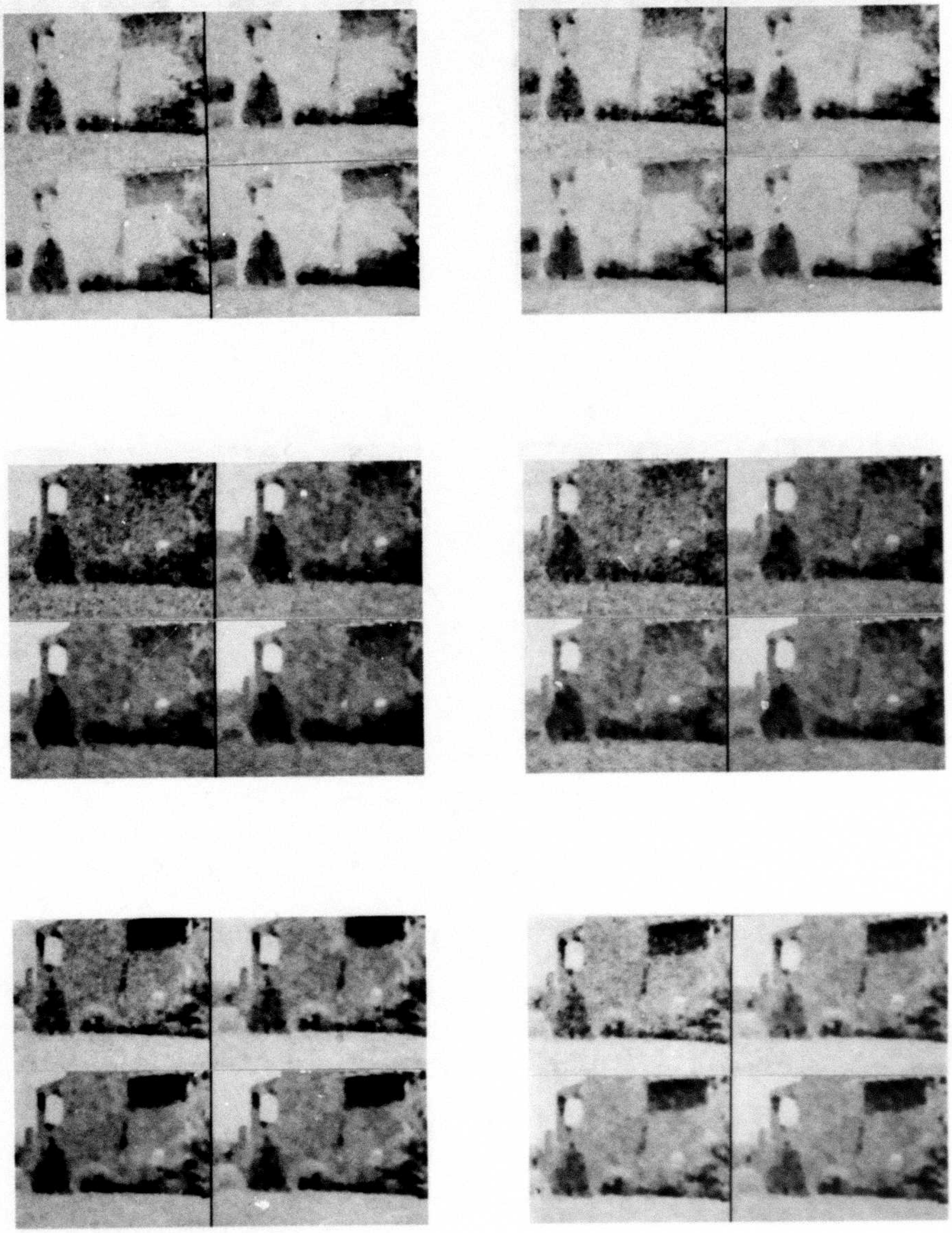


(c)



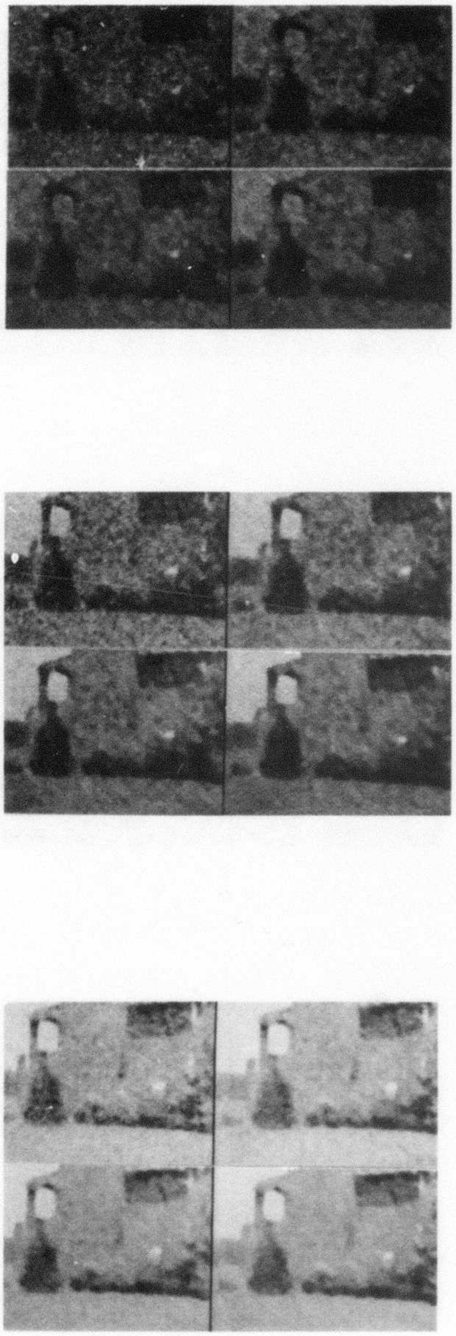
(d)

Figure 13 continued

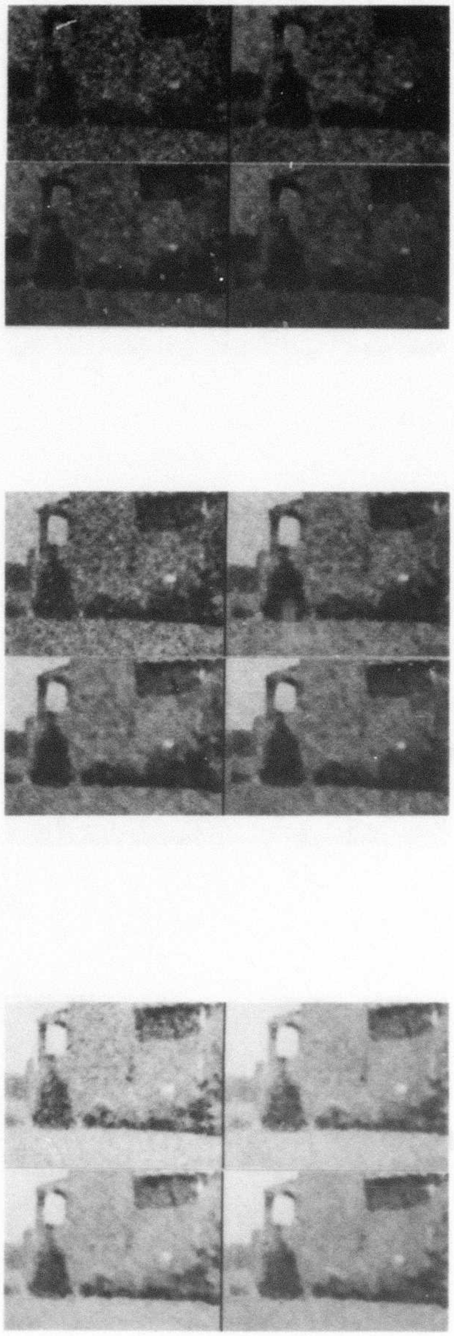


(a) (b)

Figure 14. Gradient Smoothing

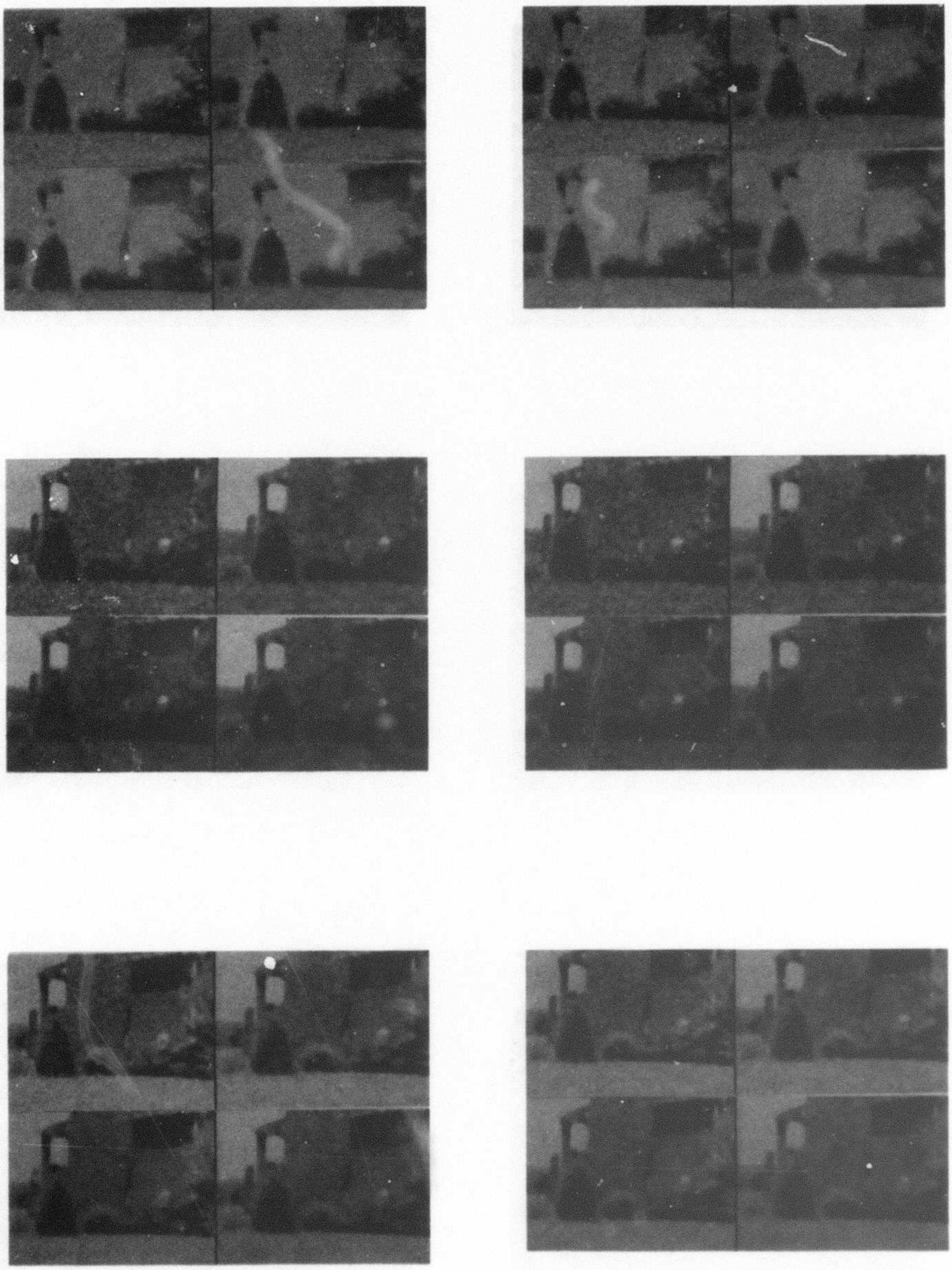


(c)



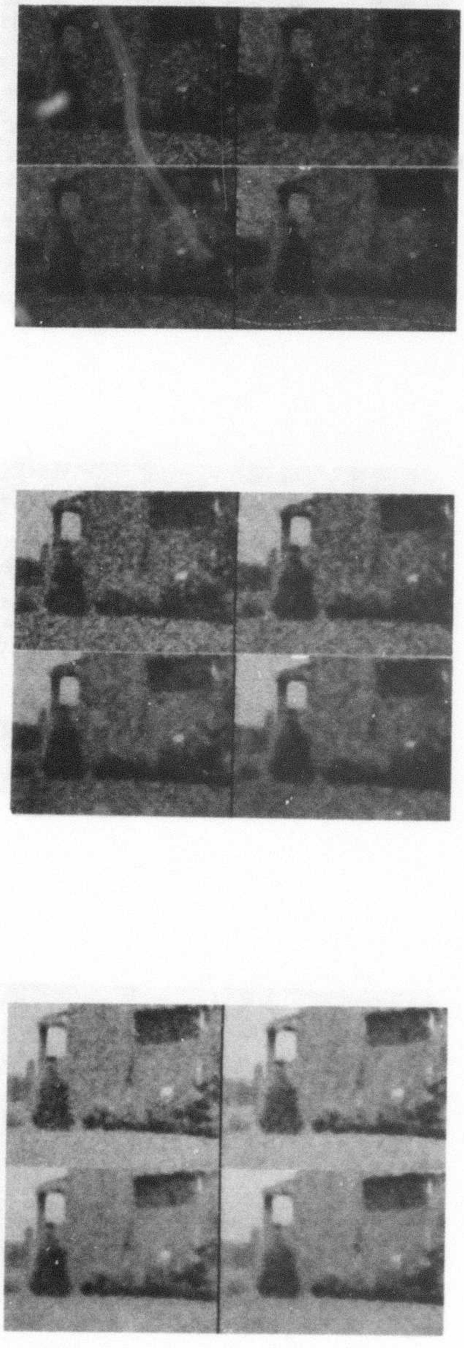
(d)

Figure 14 continued



(a) (b)

Figure 15. Neighbor-weighting Method 1.



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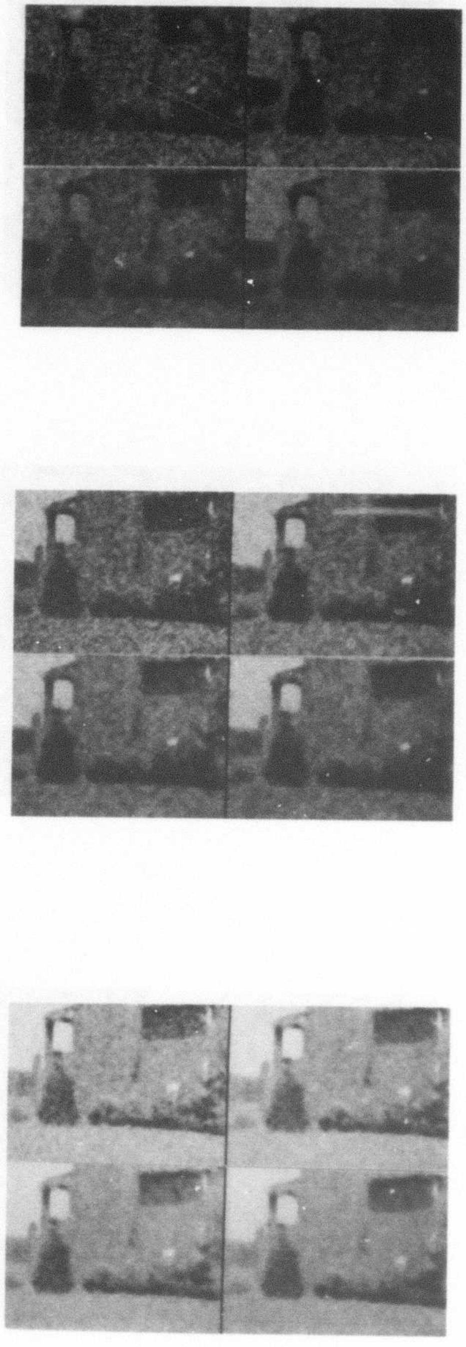
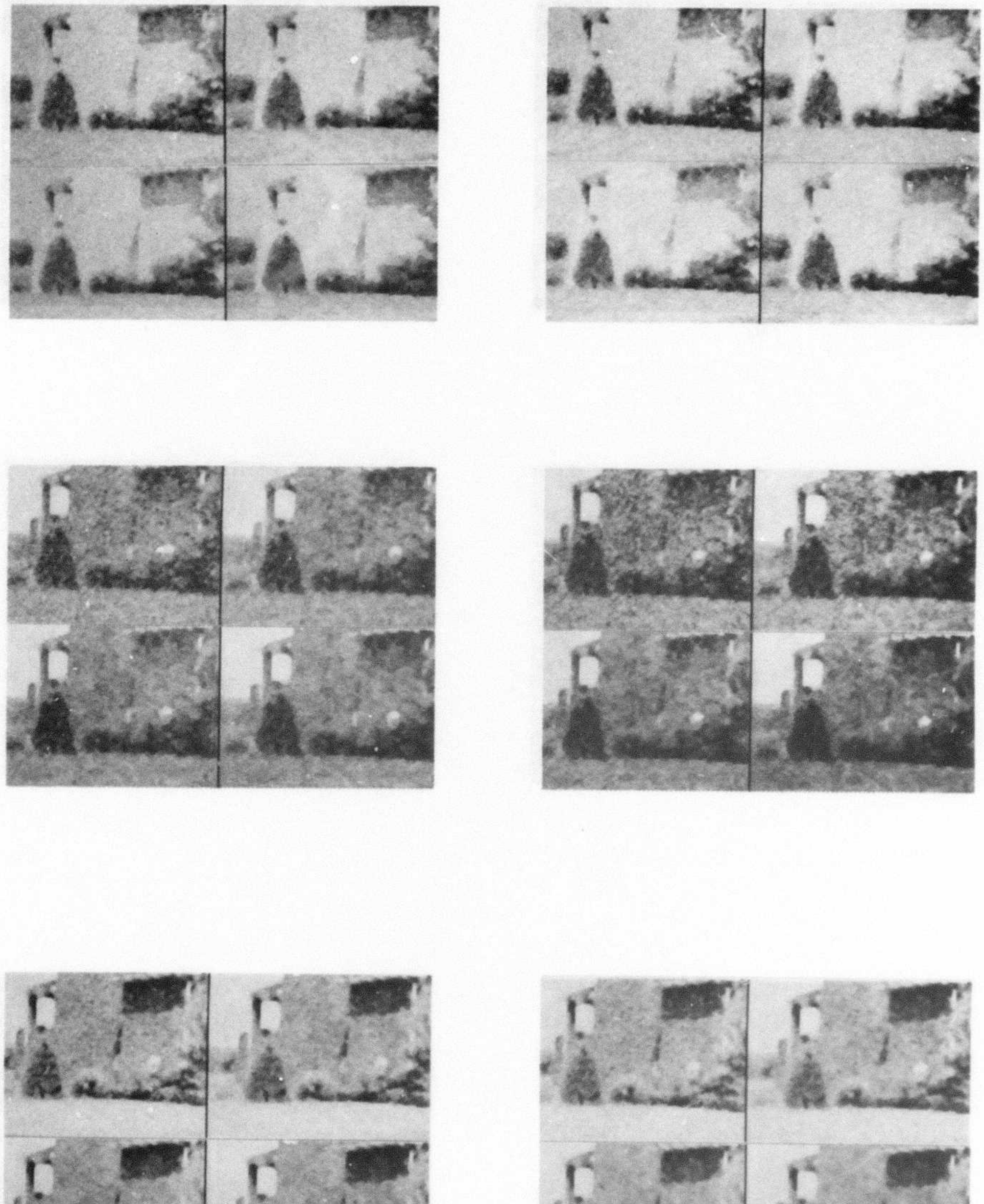


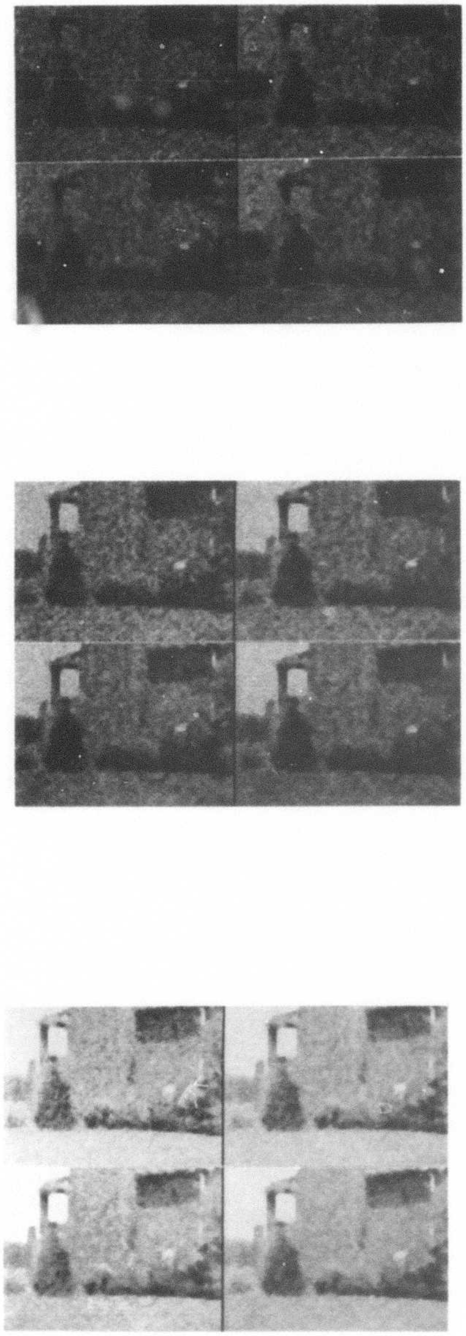
(d)

Figure 15 continued



(a) (b)

Figure 16. E^5



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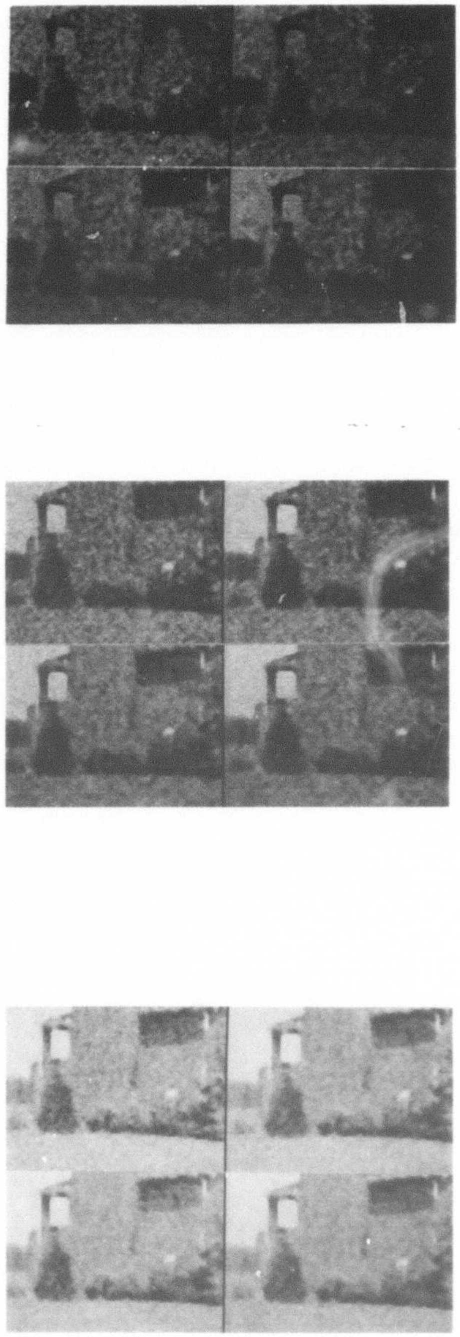
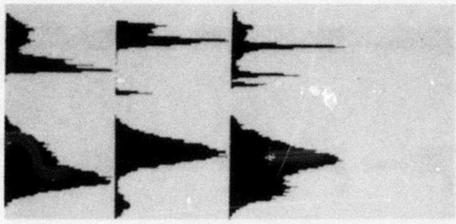
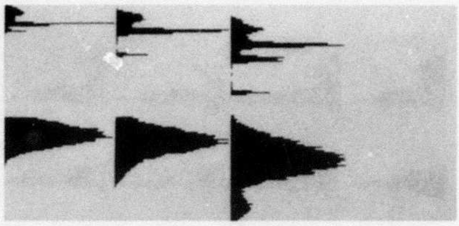


(d)

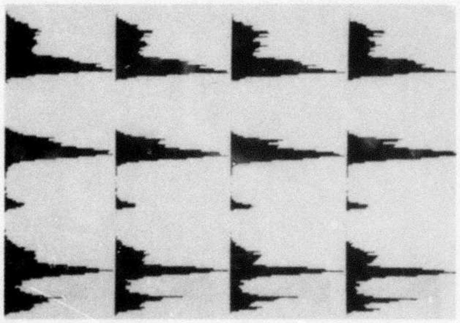
Figure 16 continued

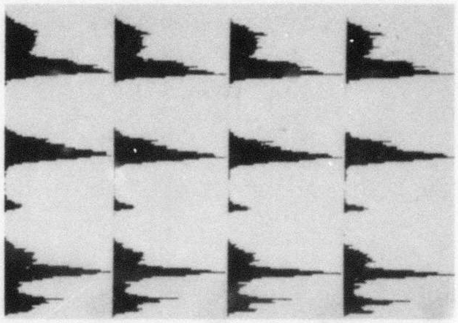




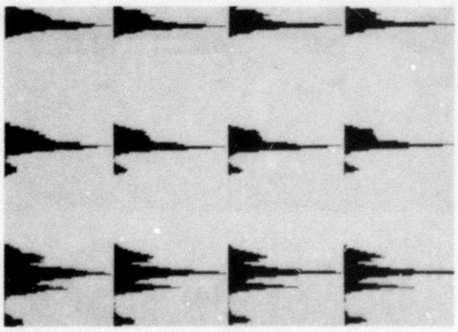
RGB UVW

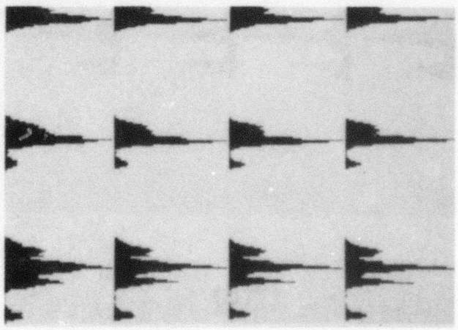
Figure 17.





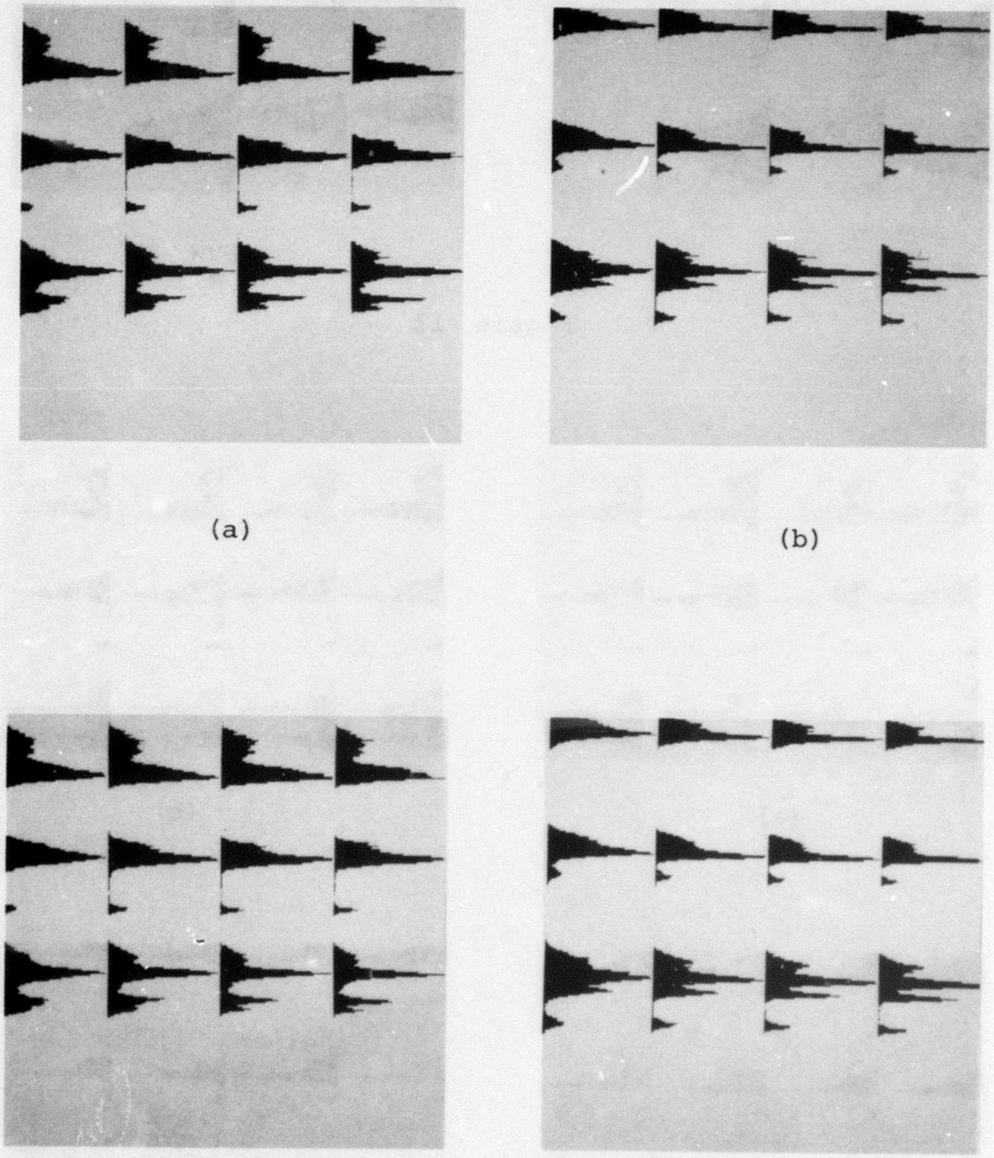
(a) (b)





(c) (d)

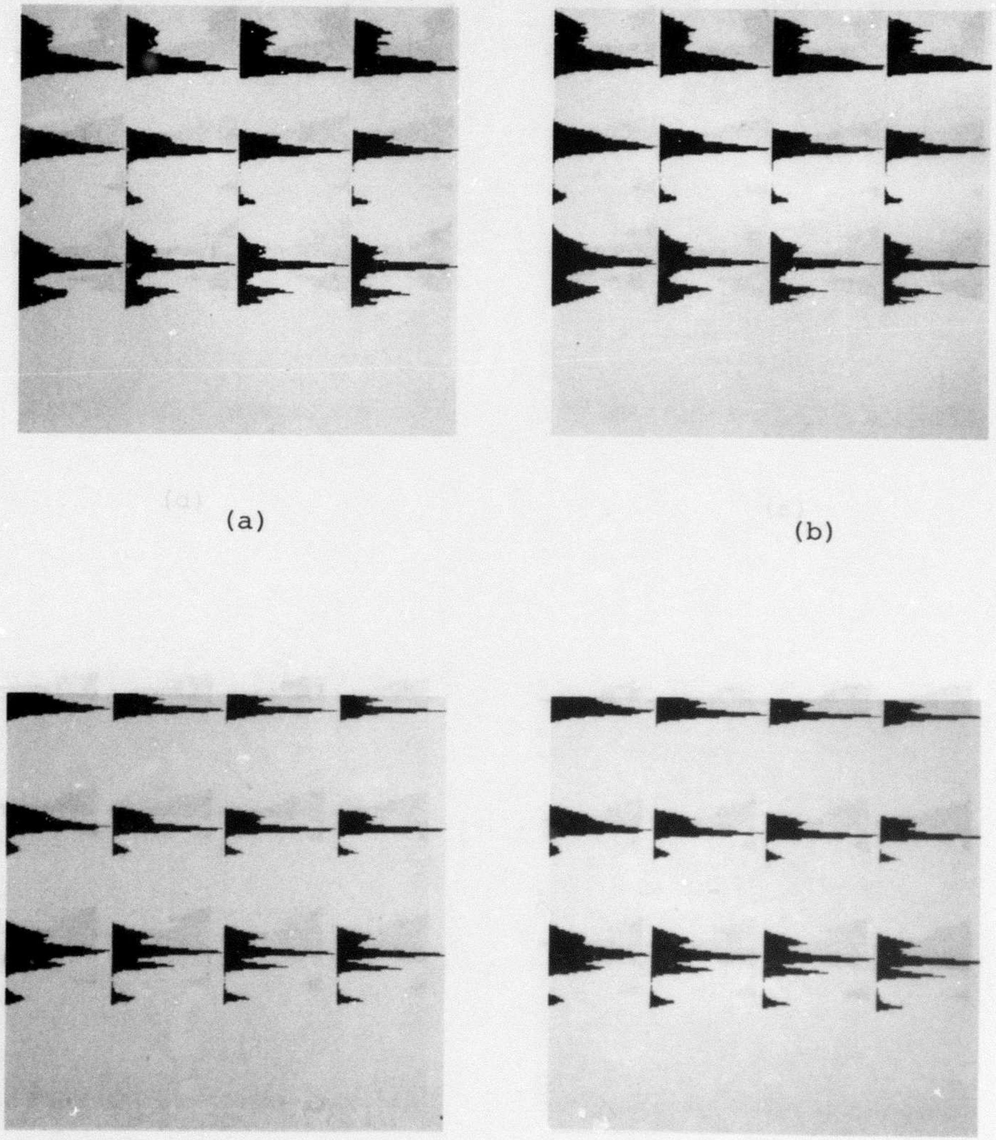
Figure 18. Median Filtering



(a) (b)

(c) (d)

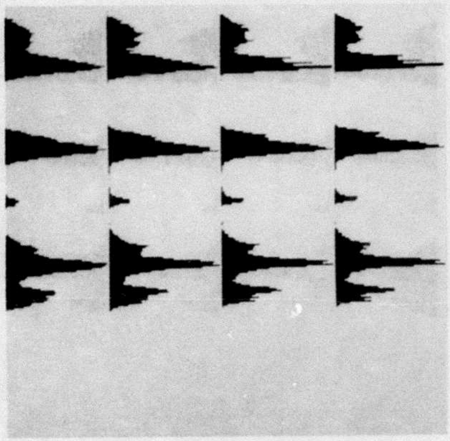
Figure 19. Gradient Smoothing



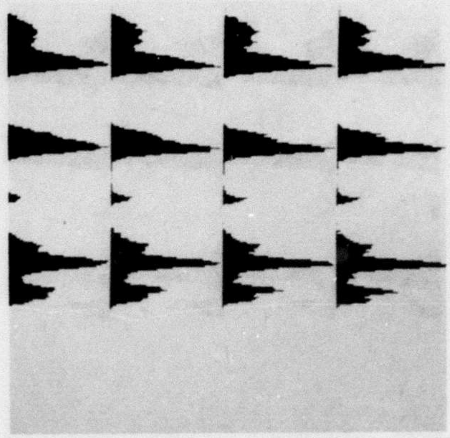
(a) (b)

(c) (d)

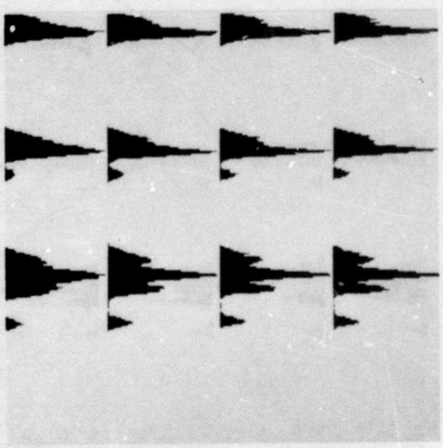
Figure 20. Neighbor-weighting Method 1.



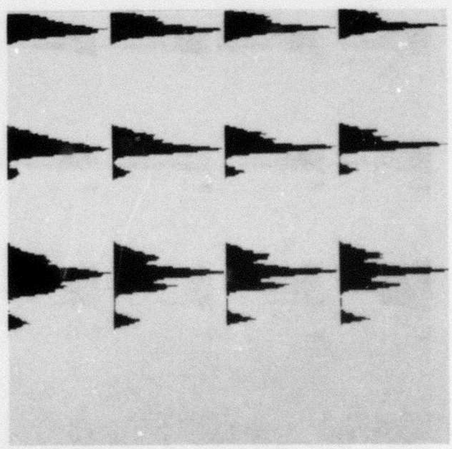
(a)



(b)



(c)



(d)

Figure 21. E^5

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An earlier report compared a number of iterative local noise cleaning techniques as applied to grayscale images. The present report provides some additional discussion of the grayscale results, and also applies several of the better methods to a color image of a house. Noise cleaning on each individual color component is compared with noise cleaning on the color vectors themselves. Results for two color coordinate systems, RGB and UVW, are also compared.

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